Inelastic dynamic analysis of shells with the TRIC shell element

Manolis Papadrakakis*, Zacharias S. Mouroutis, Lucia Karapitta and A.G. Papachristidis

Institute of Structural Analysis & Seismic Research
National Technical University Athens, Zografou Campus, Athens 15780, Greece
e-mail: {mpapadra,zachmour,klucia}@central.ntua.gr

The dynamic analysis of shells has attracted considerable interest in recent years. As analysts are increasingly performing more sophisticated simulations of complex structural models (some problems may comprise hundreds of thousands or even millions degrees of freedom) there is a great need for simple, and at the same time, accurate elements to conduct large-scale computational experiments. Furthermore, most available shell elements lack generality, that is, they are either isotropic or composite. In addition there is a trend in finite element analysis for numerical integration that calls for stiffness and mass matrices containing simple algebraic expressions. To satisfy these requirements, a lot effort has been devoted to expand and further develop the natural mode finite element method for the analysis of isotropic and laminated composite shell structures; the latter relies heavily on physical arguments and differs markedly from classical finite element methods. The product of this effort is the TRIC (TRIangular Composite) element, which has been presented in previous papers.

TRIC is a facet triangular shell element, which is based on the natural mode method. It is an element that has been tested and proved to be very efficient in linear and nonlinear static problems. It has been shown that the TRIC shell element satisfies the individual element test and according to the non-consistent formulation its use guarantees convergence. Moreover, another major advantage in the formulation of this element is the incorporation of the transverse shear deformations in a way that defies the shear-locking phenomenon.

In this work we present the derivation of the consistent mass matrix of the TRIC element so that it can be used in linear and nonlinear dynamic problems. Both translational and rotational inertia are included in the mass matrix, which is conceived, using kinematical and geometrical arguments consistent with the assumed natural rigid-body and straining modes of the element.

Furthermore, a layered elasto-plastic constitutive model based on the von Mises yield criterion, associated flow rule and kinematic hardening model according to Ziegler's hardening law have been incorporated in the geometrical nonlinear dynamic formulation. To obtain the actual state of stress and plastic internal variables, a return-mapping procedure according to closest point projection algorithm in stress space has been considered. The linearization of this computational scheme leads to consistent elasto-plastic constitutive matrix. The main advantage of the present natural mode approach is that the elasto-plastic stiffness matrix is formed on the natural coordinate system and can be expressed analytically for each layer.

Finally, the element's robustness and accuracy will be shown in a variety of properly selected test examples exhibiting highly geometrical and material nonlinear dynamic behavior, while its computational efficiency will be demonstrated by comparing the CPU performance of the element with the other available shell elements.

REFERENCES

[1] J.H., Argyris, L. Tenek and L. Olofsson, "Nonlinear free vibrations of composite plates." Comput. Methods Appl. Mech. Engrg., 115 (1994) 1-51.

[2] J.H., Argyris, M. Papadrakakis and L. Karapitta, "Elasto-plastic analysis of shells with the triangular element TRIC." Comput. Methods Appl. Mech. Engrg., 191 (2002) 3613-3636.